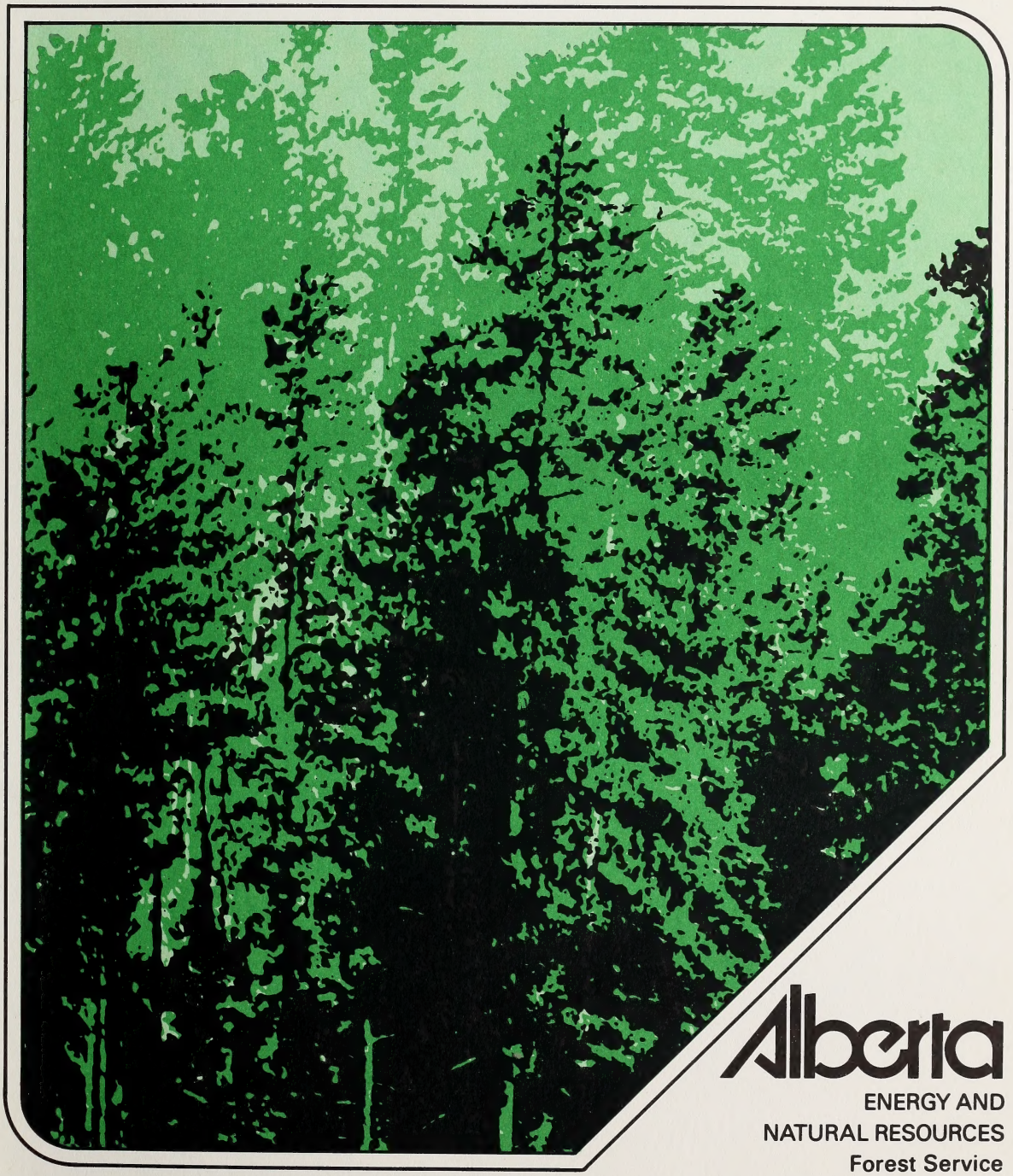
Reclamation with Native Grasses in Alberta: Field Trial Results



Alberta

ENERGY AND
NATURAL RESOURCES
Forest Service

RECLAMATION WITH NATIVE GRASSES IN ALBERTA: FIELD TRIAL RESULTS

by
Russell Ecological Consultants
Edmonton, Alberta

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ABSTRACT

Between 1978 and 1981 the Alberta Forest Service established 10 native grass field trials. The general objectives were: (1) to select the most promising native grass species for reclamation of high elevation disturbances in the Eastern Slopes; (2) to design and evaluate native grass seed mixtures; and (3) to develop recommendations for establishing and maintaining native grasses on high elevation disturbances. This report gives the first long-term results from these trials.

Species performances were generally poor in the species adaptability trials at Cadomin. The wheatgrasses, especially Agropyron dasystachyum, A. trachycaulum and A. trachycaulum 'Revenue' performed best overall. Phleum alpinum, Poa interior and Trisetum spicatum were considered failures. Contrastingly, most species performed reasonably well in the species adaptability trial at Mildred Lake. On both trial sites the cultivated species performed equally as well as their native counterparts.

The performance of the native grass mixture was poor in the nurse crop x fertilizer rate x seeding rate trials at Cadomin. Fertilization produced a significant increase in plant cover. Neither the nurse crop nor the seeding rate treatments had any significant effect on the performance of the seed mixture.

Seed mixtures containing wheatgrass species, especially A.

dasystachyum, performed best in the four seed mixture trials. In contrast, the only seed mixture lacking a wheatgrass generally had the poorest results. The cultivated companion crops had little or no effect on the plant cover of the native grass mixtures. The best native grass mixtures performed equally as well as the best cultivated grass-legume mixtures.

In the establishment methods trial at Cadomin the most successful treatments were those that covered and protected the seed. Drill seeding and broadcast seeding followed by application of a mulch produced the highest plant covers. The hydroseeding treatments, in which the seed and mulch were applied together, gave the lowest plant covers. The results from this trial suggested that native grasses, if established properly, can produce adequate cover for erosion control purposes.

The revegetation treatments were generally more successful on the native mineral soil than the coarser textured overburden. Most species produced higher plant cover on the mineral soil. Furthermore, the mineral soil supported substantially higher species richness (number of species), indicating the plant communites were more diverse on mineral soil than overburden.

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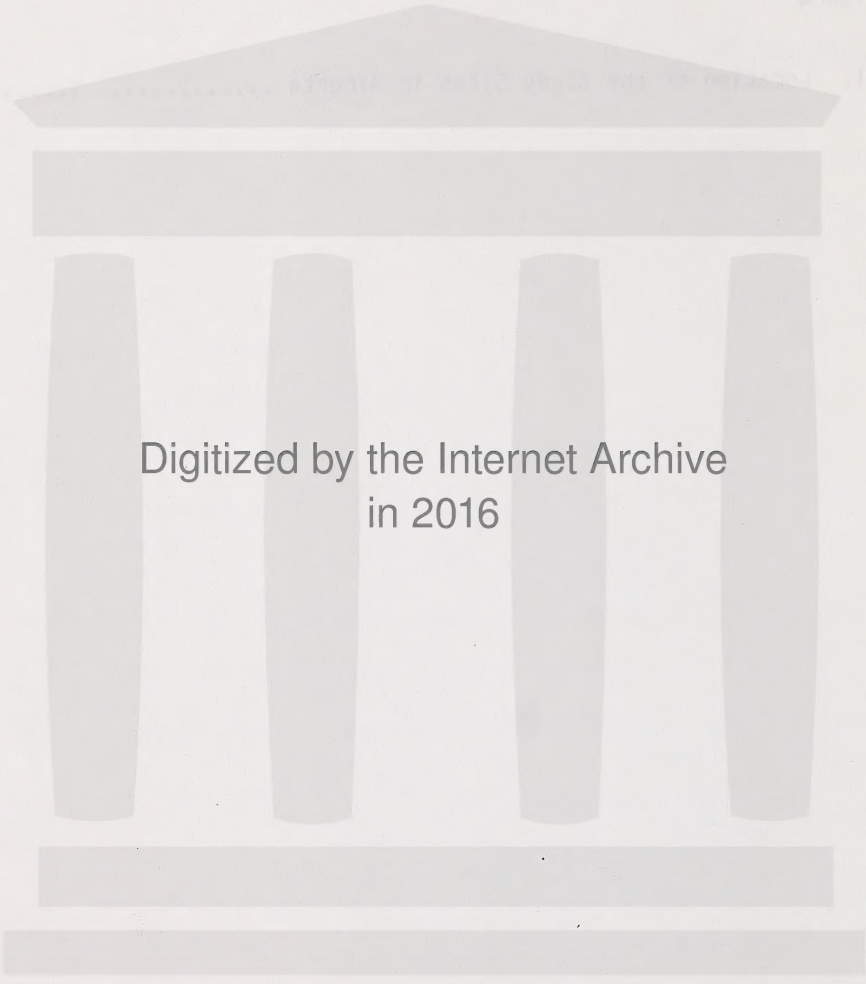

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PREFACE

Plant cover was estimated visually in this study and thus subject to bias. The concept of cover used for this report was probably more conservative than that used by earlier researchers in this study; which may partially explain why cover estimates in this report were generally lower than those in some previous reports. Also, in some earlier reports, species not seeded (i.e. invaders) were included along with seeded species in the estimates of total plant cover. For this report, only the seeded species were included in the estimate of total plant cover.

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1. INTRODUCTION

Recognizing the need for "adapted" plant species in high elevation reclamation, the Alberta Forest Service began field testing native grasses in the mid-1970s. Between 1978 and 1981, 10 native grass field trials were established, primarily on high-elevation, abandoned coal mines in the Eastern Slopes.

The long-term objectives of this research program were: (1) to select the most promising native grass species for reclamation of high elevation disturbances in the Eastern Slopes; (2) to design and evaluate native grass seed mixtures for erosion control, wildlife habitat improvement and improvement of recreation areas at high elevation sites; and (3) to develop recommendations for establishing and maintaining native grass seed mixtures on high elevation disturbances in the Eastern Slopes (Russell 1979).

The program included three "species adaptability" trials, which compared the performances of several native grasses with the aim of identifying the more promising species. Two trials evaluated the effects of nurse crops and initial fertilizer and seeding rates on the performance of a native grass seed mixture. Four trials compared the performances of several native grass and cultivated grass-legume seed mixtures. Finally, one trial examined methods of enhancing the establishment of a native grass mixture. Many of the trials were

established both on raw overburden spoils and overburden topdressed with 20 cm of native mineral soil, thus allowing an evaluation of topsoiling as a treatment.

First and/or second year results from these trials are presented in earlier progress reports (Russell and Takyi 1979, Takyi 1981, Takyi and Russell 1980, Tomm 1982, Tomm and Russell 1981). This report gives the results of the 1985 assessments and is the first long-term progress report.

2. STUDY AREA DESCRIPTION

The trials were established at three locations in Alberta (Figure 1): (1) the abandoned Cadomin (east) coal mine; (2) the abandoned Adanac coal mine; and (3) the Alberta Oil Sands Environmental Research Program (AOSERP) Mildred Lake field camp. What follows is a brief description of each site. More detailed descriptions can be found in Root (1976), Russell and Takyi (1979), Takyi (1980), Takyi and Russell (1980), and Tomm (1982).

2.1 Cadomin

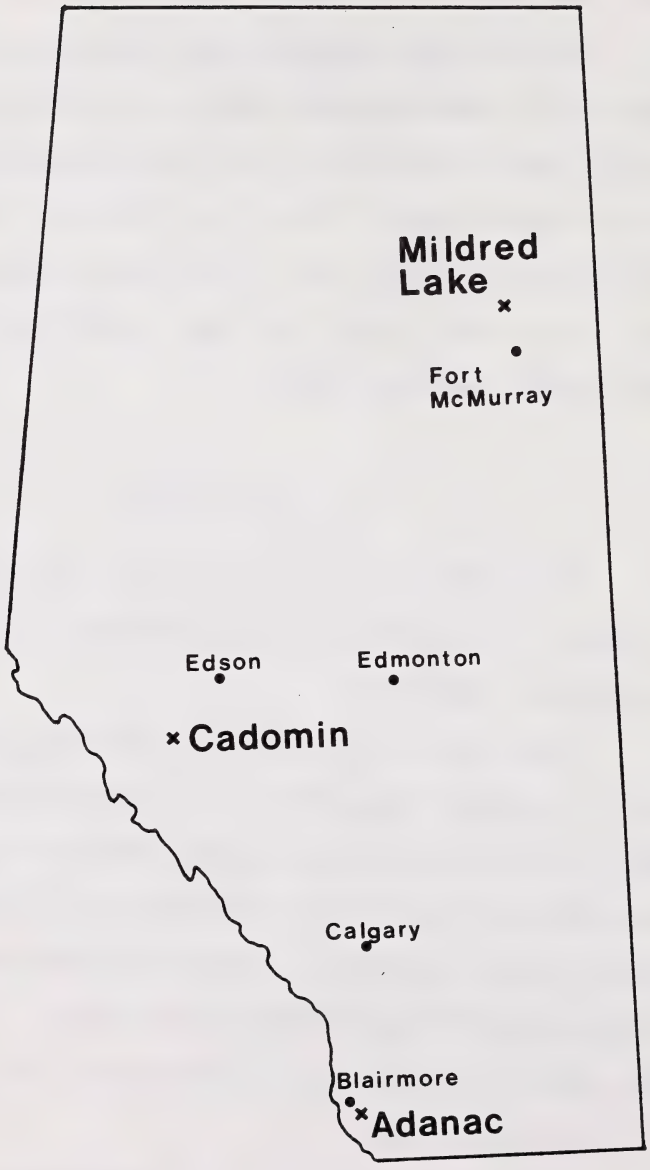
The Cadomin strip mine is located 1.6 km southeast of the town of Cadomin (S 1/2 32-46-23-W5M) at an elevation of 1 675 m. It has been abandoned since 1952.

The site is in the Subalpine Ecoregion of Strong and Leggat (1981). The natural vegetation on the abandoned spoil heaps is still sparse, consisting of isolated grasses and forbs in open communities. Large expanses of nearly barren landscape still occur. The site is exposed to prevailing westerly winds which reduce winter snow cover and increase potential evapotranspiration in summer. It is likely the strong winds are a major factor contributing to the slow revegetation of this site (Root 1976).

The trials themselves were established on overburden spoils

Figure 1

LOCATION OF THE STUDY SITES IN ALBERTA



and locally obtained native mineral soils that were applied as a topdressing to the overburden. Both soil mediums were non-saline, had adequate available K, and were very low in available N. Available P was very low in the overburden and low to moderate in the mineral soil. The overburden was strongly alkaline (pH of 8.4 to 8.9) while the mineral soil was nearer to neutral in reaction (pH of 6.5 to 7.1). The overburden was very coarse, composed primarily of rock fragments (61% by weight) and sand particles (50 to 75% of < 2 mm). The mineral soil had lower rock (28%) and sand (53%) contents and higher total exchange capacity than the overburden and was expected to be more favorable for plant growth (Islam and Takyi 1984, Russell and Takyi 1979, Takyi 1981, Tomm and Russell 1981).

2.2 Adanac

The trial site is located on the Hastings Ridge approximately 12 km south of Blairmore (LSD 10-24-6-4-W5M) at an elevation of 1 895 m. Like the Cadomin site Adanac is in the Subalpine Ecoregion and is exposed to strong winds.

The trials were established on raw overburden and a locally obtained native mineral soil spread as a topdressing on the overburden. Both materials were non-saline, low in available N, and moderately low in available P. The overburden was acidic (pH of 4.6) and the mineral soil near neutral in reaction (pH of 6.4). The overburden was dominated by rock fragments (65% by weight) and sand (69% of < 2 mm). The mineral soil had lower rock content (48%), was

not as sandy (42%), and was expected to be a better medium for plant growth.

2.3 Mildred Lake

The trial site is near the AOSERP Mildred Lake field camp approximately 38 km north of Fort McMurray (NE 18-93-10-W4M). The site is in the Dry Subregion of the Boreal Mixedwood Ecoregion (Strong and Leggat 1981) at an elevation of 314 m. In contrast to the subalpine sites the Mildred Lake site occurs in a small forest clearing and is relatively protected from winds.

The trial was established on a mixture of native sand, peat, and overburden clay designed to simulate an oil sands reclamation situation (see Section 4.1). The mixture was alkaline (pH of 7.5), non-saline, and low in available N, P and K. The organic matter content was 11.6% (Alberta Forest Service unpublished data).

3. SPECIES ADAPTABILITY TRIALS - CADOMIN
(Established by W.B. Russell and S.K. Takyi. The earlier progress reports were written by them.)

3.1 Methods

Two identical field trials were established at Cadomin in June 1978 to test the adaptability of 13 native and two cultivated grass species. One trial was on raw overburden and the other on overburden topdressed with 20 cm of mineral soil. The mineral soil had been stripped in a nearby subalpine forest and spread on the trial site in the fall of 1977. Both trials were fenced to exclude ungulates and vehicles.

Each trial used an identical, randomized complete block design with four blocks. The size of each plot was 2 x 2 m. Seed was broadcast by hand at a rate of 5 000 seeds/m^2 and raked into the soil. All plots received hand spread fertilizer at establishment (71 kg N/ha, 50 kg P/ha, 65 kg K/ha) and have not been fertilized since. Further details on establishment methods are given in Russell and Takyi (1979).

Eighth-year assessments were made August 8, 1985 of: (1) per cent total plant cover of the seeded species; (2) per cent plant cover of each species individually; (3) per cent bare-ground cover; (4) per cent litter cover; (5) vigor of the seeded species; (6) above-ground

living biomass; (7) density of flower-bearing tillers; and (8) species richness (number of species). The cover estimates and tiller counts were made in two randomly placed 0.5 x 0.5 m quadrats in each plot. The averages of the two estimates were used in the data analyses. Cover was estimated visually and was taken as the per cent of ground area covered by a vertical projection to the ground surface. Species richness was the total number of species found in the two quadrats. Species vigor was estimated subjectively using an eight point scale ranging from dead (0) to highly vigorous (7). Biomass was clipped at a height of 2 cm in two randomly placed 0.25 x 0.5 m quadrats. The two samples were bulked, for a minimum of 10 days, allowed to air dry and oven dried overnight at 65°C and weighed.

The cover estimates for plants, litter and bare-ground may not always total 100% because: (1) the estimates were made individually with no attempt to force them to total 100%; (2) invading plant species were excluded from the total plant cover estimates; and (3) there was often considerable overlap between plant cover and underlying litter cover.

Analyses of variance were conducted to determine the main effects of the treatments (species) on each of the dependent variables. To determine the main effects of soil medium analyses of variance were conducted on the variables using the block means from both trials as raw data. Duncan's new multiple range tests were used to determine the significance of differences among treatment means. Species performances in terms of plant cover were compared between the two soil mediums by t-tests. All statistics were computed using the

SPSSx program package (SPSSx 1983).

3.2 Results and Discussion

Most species performed poorly on both soil mediums. Mean plant cover varied significantly among the species but never exceeded 10% (Table 1). The highest covers were achieved by Agropyron trachycaulum 'Revenue' on overburden and Festuca rubra and F. rubra 'Boreal' on mineral soil. Several species developed almost no plant cover at all, including Phleum alpinum, Poa interior and Trisetum spicatum. Most species had higher mean cover on mineral soil than overburden; but only for F. rubra and F. rubra 'Boreal' were the differences statistically significant ($P < 0.05$).

Above-ground biomass varied significantly among the species but was generally low (less than 215 kg/ha). The most productive species on both mediums was the cultivar Agropyron trachycaulum 'Revenue' (Table 1).

Species richness varied significantly among the species on overburden but not mineral soil (Table 1). On overburden, plots with the highest species richness tended to have the lowest plant covers, suggesting species producing high plant cover inhibited invasion. In fact species richness was found to be negatively correlated with plant cover ($P < 0.01$) in both trials and with litter cover ($P < 0.05$) in the overburden trial (see Section 6.2).

The vigor ratings were generally low, reflecting the poor species performances (Table 1). The highest ratings were achieved by

Table 1

EFFECTS OF SPECIES ON PLANT COVER, ABOVE-GROUND BIOMASS, SPECIES RICHNESS, AND VIGOR IN THE ADAPTABILITY TRIALS AT CADOMIN ON OVERBURDEN (OB) AND MINERAL SOIL (MS)

	Plant cover (%)		Biomass (g/0.25m^2)		Richness (no./0.25m^2)		Vigor	
Species	OB	MS	OB	MS	OB	MS	OB	MS
Agropyron dasystachyum	4.9ab[1]	6.6ab	1.82ab	4.77ab	1.3a	4.8a	3.0a	3.8ab
Agropyron subsecundum	1.9cd	7.3ab	1.00bcd	2.97abc	1.5a	6.0a	2.3ab	3.3ab
Agropyron trachycaulum	3.9abc	5.1abc	2.27a	4.25ab	1.0a	5.5a	2.5ab	3.5ab
A. trachycaulum 'Revenue'	5.4a	7.5a	3.72	5.35a	1.0a	5.0a	2.5ab	2.8bc
Calamagrostis purpurascens	3.8abc	4.6abc	1.29bc	2.45bcd	1.3a	5.8a	2.5ab	4.0a
Deschampsia caespitosa	0.2d	1.9bc	0.00f	0.05d	3.0a	6.8a	1.0de	1.0de
Festuca idahoensis	2.7bcd	2.7abc	0.62cdef	1.32cd	2.0a	6.0a	2.3b	3.3ab
Festuca rubra	1.0d	8.1a	0.15ef	0.82cd	1.3a	3.3a	1.3cde	3.0ab
F. ruba 'Boreal'	2.4cd	8.1a	0.37def	1.10cd	1.0a	4.0a	1.8bcd	3.0ab
Festuca saximontana	1.1d	0.5c	0.00f	0.00d	2.0a	5.8a	1.8bcd	1.8cd
Koeleria cristata	4.1abc	5.1abc	0.62cdef	0.87cd	1.5a	5.0a	2.3ab	3.8ab
Phleum alpinum	0.0d	0.1c	0.00f	0.00d	3.5a	5.8a	0.0f	0.5e
Poa interior	0.3d	0.9c	0.00f	0.00d	1.5a	6.8a	0.8e	2.8bc
Stipa columbiana	4.1abc	0.6c	0.94bcde	0.30d	1.5a	8.0a	2.0bc	1.8cd
Trisetum spicatum	0.0d	0.4c	0.00f	0.00d	1.8a	5.8a	0.0f	1.8cd

[1] Means followed by the same letter within a column are not different at the 5% level of significance (N=4).

Agropyron dasystachyum on overburden and Calamagrostis purpurascens on mineral soil.

The density of flower-bearing tillers varied considerably among species. A. trachycaulum 'Revenue' and Poa interior had the highest densities on both soil mediums (Table 2). Many species produced few or no flowering tillers, suggesting they may have low reproductive success on this site. A. dasystachyum reproduced vegetatively by rhizomes and had many tillers, but produced very few flower-bearing tillers.

There was considerable variability among species in litter cover (Table 2). A. trachycaulum 'Revenue' and A. trachycaulum produced the highest litter covers on overburden; whereas on mineral soil A. dasystachyum had the highest litter cover.

Bare-ground cover is the proportion of ground surface that is exposed and, hence, succeptible to erosion. Species with the lowest bare-ground covers were those with the highest plant and litter covers. A. trachycaulum 'Revenue' and A. trachycaulum had the lowest bare-ground cover on overburden and A. dasystachyum on mineral soil (Table 2).

The type of soil medium had a significant effect on four of the seven dependent variables (Table 3). The mineral soil supported higher plant cover, species richness and litter cover and lower bare-ground cover than the overburden. However, for most of these variables the differences between the two mediums were small. Only species richness was considered to be substantially higher on mineral soil. Thus, the mineral soil appeared to be slightly better than overburden

Table 2

EFFECTS OF SPECIES ON FLOWER-BEARING TILLER DENSITY, LITTER COVER, AND BARE-GROUND COVER IN THE ADAPTABILITY TRIALS AT CADOMIN ON OVERBURDEN (OB) AND MINERAL SOIL (MS)

Species	Flower-Bearing Tiller Density (no./0.25m^2)		Litter Cover (%)		Bare-Ground Cover (%)	
	OB	MS	OB	MS	OB	MS
Agropyron dasystachyum	0.4c[1]	0.3d	15.3bc	33.9a	82.3cd	61.4d
Agropyron subsecundum	2.6bc	2.3bcd	4.9cd	16.3bc	92.9abcd	69.6cd
Agropyron trachycaulum	4.6abc	9.5abc	30.4a	18.3bc	69.5e	74.0abcd
A. trachycaulum 'Revenue'	10.4a	12.8a	32.5a	22.1ab	65.6e	69.4cd
Calamagrostis purpurascens	1.9c	9.9ab	3.7cd	13.6bc	93.6abcd	80.9abc
Deschampsia caespitosa	0.0c	1.0d	4.4cd	16.3bc	94.4abc	77.0abcd
Festuca idahoensis	3.6bc	3.bcd	2.2d	10.3bc	95.8ab	83.5abc
Festuca rubra	0.0c	2.4bcd	5.4bcd	16.6bc	94.4abc	78.9abc
F. ruba 'Boreal'	1.6c	1.4cd	12.4bcd	22.6ab	86.4bcd	71.0bcd
Festuca saximontana	1.6c	0.0d	3.8cd	13.0bc	95.1ab	80.4abc
Koeleria cristata	2.9bc	3.8bcd	5.0cd	13.4bc	91.8abcd	81.1abc
Phleum alpinum	0.0c	0.0d	2.7d	8.4c	96.5ab	87.8a
Poa interior	7.9ab	17.8a	0.7d	8.0c	99.1a	86.9ab
Stipa columbiana	1.3c	0.4d	16.6b	19.3bd	81.9d	70.5bcd
Trisetum spicatum	0.0c	0.4d	0.4d	11.9bc	99.6a	83.8abc

1 Means followed by the same letter within a column are not different at the 5% level of significance (N=4).

Table 3

EFFECTS OF SOIL MEDIUM ON SEVEN VARIABLES
IN THE SPECIES ADAPTABILITY TRIALS
AT CADOMIN

Variable	Overburden	Mineral Soil
Plant Cover (%)	2.4	4.0
Above Ground Biomass ($g/0.25m^2$)	0.86a[1]	1.62a
Species Richness (no. species/$0.25m^2$)	1.7	5.6
Vigor	1.7a	2.6a
Flower-Bearing Tiller Density (no. tillers/$0.25m^2$)	2.6a	4.3a
Litter Cover (%)	9.4	16.3
Bare-Ground Cover (%)	89.3	77.1

1 Means followed by the same letter within a row are not different at the 5% level of significance (N=4).

for plant cover development but considerably better for species invasion.

3.3 Conclusions

Species performances were generally poor. All species had low plant covers and biomass yields. Seed drift caused by the strong westerly winds probably contributed to the poor plant establishment and development (Russell and Takyi 1979).

Of the 15 species the wheatgrasses, especially Agropyron trachycaulum 'Revenue', A. trachycaulum and A. dasystachyum, performed best overall. Festuca rubra and F. rubra 'Boreal' did relatively well on mineral soil but poorly on overburden. The two cultivars A. trachycaulum 'Revenue' and F. rubra 'Boreal' performed as well or better than their native counterparts. The following species did very poorly on both soil mediums and were considered failures: Phleum alpinum, Poa interior, and Trisetum spicatum.

The mineral soil supported slightly higher plant cover and was more favorable for species invasion than the overburden.

4. SPECIES ADAPTABILITY TRIAL - MILDRED LAKE
(Established by H.O. Tomm. The earlier progress report was written by him.)

4.1 Methods

The trial site was prepared in 1979 to simulate a reclamation situation on tailings sand. The upper soil horizon (A) was stripped to expose the sandy B and C horizons. From stockpiles at Syncrude clay dominated overburden and peat were then hauled to the site and spread on the sand in two 15 cm layers. Finally, the peat and clay were tilled 15 cm deep into the sand. A low, fine-mesh fence was erected to exclude rodents.

The trial was established in June 1981 to test nine native and eight cultivated grass species. A complete randomized block experimental design was used with three blocks. All plots were 2 x 2 m in size.

The seed was spread in hand dug furrows at a rate of 100 seeds/m to simulate drill seeding. Each plot had 10 furrows spaced 20 cm apart and received 2 000 seeds. Light weight seeds were buried at a depth of 0.5 cm and heavier seeds at 1 cm. After seeding, an inorganic 10-30-10 fertilizer was applied at a rate of 600 kg/ha. No additional fertilizer has been applied since. Further details on establishment methods are given in Tomm (1982).

Fifth-year assessments were made August 27, 1985. The dependent variables, methods of assessment and methods of data analysis were the same as described in Section 3.1.

4.2 Results and Discussion

While no species demonstrated clear superiority in this trial most performed reasonably well and none failed. Koeleria cristata and Festuca rubra 'Boreal' had the highest mean plant covers, although several other species were not significantly lower (Table 4). Above-ground biomass varied widely among species but was highest for Agropyron trachycaulum. Poa alpina and P. pratensis 'Nugget' had reasonably high plant cover but very low biomass. This resulted from clipping at a height of 2 cm, which left unclipped much of the biomass of the lower growing species.

The species treatments had a significant effect on species richness (Table 4). Plots with Deschampsia caespitosa and Festuca saximontana had the highest richness while those with F. rubra 'Boreal', Alopecurus pratensis, and Agropyron dasystachyum 'Elbee' had the lowest.

The highest mean vigor ratings were achieved by F. rubra 'Boreal', K. cristata, and Poa compressa 'Reubens', although other species had ratings not significantly lower (Table 4). There was wide variation among species in the density of flower-bearing tillers. P. compressa 'Reubens' and P. interior had very high densities; whereas A. dasystachyum, A. dasystachyum 'Elbee', A. riparium 'Sodar', and

Table 4

EFFECTS OF SPECIES ON SEVEN VARIABLES IN THE ADAPTABILITY TRIAL AT MILDRED LAKE

Species	Plant Cover (%)	Biomass (g/0.25m^2)	Species Richness (no./0.25m^2)	Vigor	Flowering Tiller Density (no./0.25m^2)	Litter Cover (%)	Bare-Ground Cover (%)
Native							
Agropyron trachycaulum	15.7ab[1]	12.20a	4.7bc	4.0c	15.5cde	49.3cd	22.7abc
Agropyron dasystachyum	16.5ab	7.37abcd	2.0cde	3.7cd	0.2e	86.7a	2.2c
Agropyron subsecundum	7.7b	3.13cd	2.7cde	3.3cd	6.3de	29.3d	44.3a
Deschampsia caespitosa	8.0b	0.60d	7.3a	3.0d	1.5e	42.3d	20.0abc
Festuca saximontana	9.5b	2.10d	6.7ab	4.7ab	40.2b	38.5d	25.3abc
Koeleria cristata	19.5a	6.87abcd	2.3cde	5.0a	24.3bcd	43.7d	36.2ab
Poa alpina	15.3ab	0.93d	4.7bc	4.7ab	23.8bcd	30.7d	43.2a
Poa interior	7.0b	3.73cd	4.0cd	4.7ab	93.0a	35.3d	18.0abc
Trisetum spicatum	9.0b	3.33cd	3.7cde	4.7ab	34.3bc	36.5d	43.5a
Cultivated							
Agropyron cristatum 'Fairway'	11.8ab	6.83abcd	2.7cde	3.3cd	1.5e	57.8abcd	27.5abc
Agropyron dasystachyum 'Elbee'	14.5ab	5.93bcd	1.7de	3.7cd	0.0e	77.5ab	19.0abc
Agropyron riparium 'Sodar'	11.5ab	4.40cd	2.3cde	3.7cd	0.5e	85.8a	11.3bc
Agropyron trachycaulum 'Revenue'	13.8ab	9.70abc	2.7cde	4.0abc	30.7bc	83.0a	1.2c
Alopecurus pratensis	12.5ab	9.33abc	1.3de	3.7cd	0.2e	73.2abc	1.5c
Festuca ruba 'Boreal'	19.3a	6.97abcd	1.0e	5.0a	16.7cde	76.3ab	13.8bc
Poa compressa 'Reubens'	7.0b	11.33ab	2.3cde	5.0a	97.8a	81.5a	9.8bc
Poa pratensis 'Nugget'	8.3b	0.70d	3.3cde	3.3cd	36.3b	53.5bcd	13.2bc

[1] Means followed by the same letter within a column are not different at the 5% level of significance (N=4).

Alopecurus pratensis produced few or no flowering tillers.

Litter cover was generally high but varied among the species (Table 4). A. dasystachyum, A. riparium 'Sodar', A. trachycaulum 'Revenue', and P. compressa 'Reubens' had the highest litter covers. The amount of bare-ground cover differed among the species. Plots with A. trachycaulum 'Revenue', Alopecurus pratensis, and A. dasystachyum had the lowest bare-ground cover.

The cultivars in this trial performed as well as their native counterparts. The only statistically significant difference was that A. trachycaulum 'Revenue' produced higher litter cover than A. trachycaulum (Table 4).

All species planted in the adaptability trials at both Mildred Lake and Cadomin performed better at Mildred Lake (compare Tables 1 and 2 with 4). This may in part be due to the more favorable climate at Mildred Lake. Mildred Lake is lower in elevation and more protected from winds than Cadomin. Summer temperatures are expected to be higher and winter snow cover deeper at Mildred Lake; high winds on the Cadomin site periodically remove the winter snow cover (Root 1976). Furthermore, soil water availability is probably greater at the Mildred Lake site, as evidenced by the ponding of meltwater in the spring (pers. com. S.K. Takyi) and the heavy cover of mosses beneath the grass litter.

4.3 Conclusions

No species demonstrated clear superiority in this trial and

none failed. Most species performed reasonably well, suggesting the trial site offered no particular revegetation problems. All species performed better in this trial than in the adaptability trials at Cadomin.

The cultivars Agropyron dasystachyum 'Elbee' and A. trachycaulum 'Revenue' gave results as equally good as their native counterparts.

5. NURSE CROP X FERTILIZER RATE X SEEDING RATE TRIALS
(Established by S.K. Tayki and W.B. Russell. The earlier progress report was written by them.)

5.1 Methods

Two separate but identical trials were established at Cadomin in June 1978 to test the effects of four nurse crops, three fertilizer rates and two seeding rates on the performance of a native grass mixture. One trial was on raw overburden and the other on overburden topdressed with 20 cm of mineral soil (see Section 3.1). A randomized complete block experimental design was used with three blocks. The trial site was fenced to exclude ungulates and vehicles.

The native grass mixture was composed of equal numbers of seeds of *Agropyron trachycaulum* (69% by weight), *Festuca saximontana* (15%), *Poa interior* (8%), and *Trisetum spicatum* (8%). The nurse crop treatments were: (1) *Hordeum vulgare* 'Windsor' applied at 20 kg/ha; (2) *Trifolium pratense* applied at 3 kg/ha; (3) a mixture of *Festuca rubra* (40% by weight), *Trifolium repens* (12%), *Phleum pratense* 'Climax' (24%), and *Poa compressa* 'Canon' (24%) applied at 15 kg/ha; and (4) control. The fertilizer treatments were: (1) 40-20-40 (N-P-K in kg/ha); (2) 80-40-80; and (3) control. The seeding rate treatments were: (1) 1 000 seeds/m^2 (11.4 kg/ha); and (2) 5 000 seeds/m^2 (56.9 kg/ha).

The plots were 2 x 2 m in size. All seed was broadcasted by

hand and raked into the soil. Further details on establishment methods are given in Russell and Takyi (1979).

The assessment methods and data analyses were generally the same as in Section 3.1 except flower-bearing tiller density was not sampled.

5.2 Results and Discussion

Of the main effects only fertilizer rate significantly influenced any of the dependent variables. As noted in the first years' progress report (Russell and Takyi 1979) the nurse crop species did not establish well, so significant main effects due to nurse crop treatments were not expected. The seeding rate treatments had a significant effect on plant cover after the first year (Russell and Takyi 1979), but the effect was small and by the second year had apparently disappeared (Takyi and Russell 1980).

The highest fertilizer rate produced the highest plant cover, biomass, vigor, litter cover and lowest bare-ground cover in the trial on overburden (Table 5). In the mineral soil trial only vigor, litter cover and bare-ground cover responded significantly to fertilizer rate.

The responses to fertilizer rate suggest that low fertility limited plant development on both soil mediums. Since the response was stronger on overburden than mineral soil, low fertility may have been more limiting on overburden.

Overall, the performance of the seed mixture was poor, especially on overburden. The overburden in this trial was observed to

Table 5

EFFECTS OF FERTILIZER RATE ON SIX VARIABLES IN THE NURSE CROP X FERTILIZER RATE X SEEDING RATE TRIALS

Fertilizer Rate (N-P-K in kg/ha)	Overburden	Mineral Soil
	- Plant Cover (%) -	
0-0-0	0.1c[1]	6.2a
40-20-40	1.2b	8.1a
80-40-80	3.1a	9.9a
	- Biomass (g/0.25m^2) -	
0-0-0	0.08c	4.58a
40-20-40	0.67b	4.16a
80-40-80	2.46a	5.41a
	- Richness (no. species/0.25m^2) -	
0-0-0	0.7	5.2a
40-20-40	3.1a	5.3a
80-40-80	3.5a	5.9a
	- Vigor -	
0-0-0	0.3c	2.7b
40-20-40	1.3b	3.2a
80-40-80	2.4a	3.3a
	- Litter Cover -	
0-0-0	0.1b	5.8b
40-20-40	2.4b	9.1b
80-40-80	9.7a	18.4a
	- Bare-Ground Cover (%) -	
0-0-0	99.9a	85.3a
40-20-40	96.9b	80.3ab
80-40-80	88.8c	74.3b

1 Means followed by the same letter within a column for a given variable are not different at the 5% level of significance (N=24).

be particularly high in rock content, which probably contributed to the poor results.

Table 6 shows the composition of the seed mixture and the effects of fertilizer rate on mean cover of each species. Agropyron trachycaulum was the dominant species on both soil mediums and showed the greatest response to fertilizer rate. All species had higher mean cover on mineral soil than overburden.

The effects of soil medium on the dependent variables are shown in Table 7. All variables except bare-ground cover had higher mean values on mineral soil than overburden, although the differences were statistically significant only for species richness and vigor. Thus, the mineral soil was a slightly better plant growth medium than overburden.

5.3 Conclusions

The performance of the seed mixture was poor, especially on overburden. Fertilization improved the performance of the mixture on both soil mediums. The response to fertilization was stronger on overburden, suggesting low fertility was more limiting on overburden than mineral soil. Neither the nurse crop nor the seeding rate treatments had any significant effect on the performance of the seed mixture.

Agropyron trachycaulum was the dominant species in the mixture in terms of plant cover on both soil mediums. Trisetum spicatum had very lower cover and was considered a failure.

Table 6

EFFECTS OF FERTILIZER RATE ON PER CENT COVER (MEAN ± STANDARD ERROR) OF SPECIES SEEDED IN THE NURSE CROP X FERTILIZER RATE X SEEDING RATE TRIALS (N=24)

Species	Fertilizer Rate (N-P-K in kg/ha) 0-0-0	40-20-40	80-40-80
		- Overburden -	
Agropyron trachycaulum	0.05 ± 0.03	0.55 ± 0.10	2.51 ± 0.40
Festuca saximontana	0.07 ± 0.03	0.40 ± 0.10	0.49 ± 0.11
Poa interior	0.01 ± 0.01	0.16 ± 0.04	0.17 ± 0.06
Trisetum spicatum	0.00	0.01	0.01
		- Mineral Soil -	
Agropyron trachycaulum	5.16 ± 0.62	5.90 ± 1.09	8.08 ± 1.31
Festuca saximontana	0.84 ± 0.14	0.84 ± 0.11	1.02 ± 0.17
Poa interior	0.29 ± 0.06	0.19 ± 0.04	0.16 ± 0.04
Trisetum spicatum	0.09 ± 0.03	0.14 ± 0.08	0.10 ± 0.04

Table 7

EFFECTS OF SOIL MEDIUM ON SIX VARIABLES
IN THE NURSE CROP X FERTILIZER RATE X SEEDING
RATE TRIALS

Variable	Overburden	Mineral Soil
Plant Cover (%)	1.5a[1]	8.1a
Above-Ground Biomass (g/0.25m^2)	1.07a	4.72a
Species Richness (no. species/0.25m^2)	1.8	5.4
Vigor	1.3	3.1
Litter Cover (%)	4.0a	11.1a
Bare-Ground Cover (%)	95.2a	80.0a

[1] Means followed by the same letter within a row are not different at the 5% level of significance (N=3).

The performance of the seed mixture was generally better on mineral soil than overburden.

6. SEED MIXTURE TRIALS
(Established by W.B. Russell. The earlier progress report was written by H.O. Tomm and W.B. Russell.)

6.1 Methods

Four identical field trials were established: (1) at Cadomin on overburden; (2) at Cadomin on overburden topdressed with mineral soil; (3) at Adanac on overburden; and (4) at Adanac on topdressed overburden. The topdressed areas were prepared in spring 1979 by stripping undisturbed mineral soil from nearby areas and spreading it on the overburden to an average depth of 20 cm. The trial sites were fenced to exclude ungulates and vehicles.

Each trial was a factorial experiment evaluating the main effects and interactions of four native grass seed mixtures (Table 8) and five companion crop treatments. Three additional seed mixtures, composed entirely of cultivated grasses and legumes, were established separately as controls (Table 9). A complete randomized block design with three blocks were used. The companion crop treatments were as follows: (1) *Alopecurus pratensis* applied at 5 kg/ha; (2) *Phleum pratense* 'Climax' and *Trifolium repens* both applied at 5 kg/ha; (3) *Festuca rubra* 'Boreal' and *Trifolium hybridum* 'Aurora' both applied at 5 kg/ha; (4) *Lolium perenne* 'Norlea' applied at 5 kg/ha; and (5) control.

The plots were 2 x 2 m in size. All plots were fertilized at

Table 8

SPECIES COMPOSITION OF THE NATIVE GRASS SEED MIXTURES

Species	Per cent of Mixture by Weight[1]			
	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Agropyron dasystachyum	--	33	66	--
Agropyron subsecundum	--	35	--	--
Agropyron trachycaulum	68	29	--	--
Deschampsia caespitosa	--	--	19	--
Festuca saximontana	15	--	-	40
Koeleria cristata	--	3	--	16
Poa alpina	9	--	8	--
Poa interior	8	--	--	22
Trisetum spicatum	--	--	7	22
TOTALS	100	100	100	100
Rate of Application (kg/ha)	46	107	53	7

1 Each mixture was applied at a rate of 1000 seeds/m^2/species.

Table 9

SPECIES COMPOSITION OF THE CULTIVATED GRASS-LEGUME SEED MIXTURES

Species	Per cent of Mixture by Weight		
	Mixture a	Mixture b	Mixture c
Agropyron cristatum 'Fairway'[1]	20	--	32
Festuca ruba 'Boreal'[1]	40	40	32
Phleum pratense 'Climax'[1]	20	24	20
Poa compressa[2]	--	24	--
Trifolium hybridum 'Aurora'[1]	--	--	16
Trifolium repens[2]	20	12	--
TOTALS	100	100	100
Rate of Application (kg/ha)	40	40	40

1 Certified seed was used.

2 Canada No. 1 seed was used.

a rate of 80 kg N/ha, 60 kg P/ha, and 60 kg K/ha at establishment time and again at half this rate in 1980. The seed and fertilizer were broadcasted by hand and raked into the soil.

The trails were established June 28, 1979 at Adanac and July 17, 1979 at Cadomin. Further details on treatments and establishment methods may be found in Russell (1979) and Tomm and Russell (1980).

Assessments were made at the end of the sixth growing season in August 1985. The assessment methods and data analyses were the same as described in Section 3.1 except flower-bearing tillers were not sampled. When comparing the native and cultivated seed mixtures (see Table 14) the analyses of variance was done on the pure seed mixtures (without companion crops).

6.2 Results and Discussion

The main effects of seed mixtures varied among the four trials (Table 10). In the overburden trial at Cadomin the best mixtures were numbers 2 and 3 and the worst, number 4. In the other three trials there were few significant differences among the four seed mixtures, although mixtures 2 and 3 had the highest mean plant covers. Thus, while no mixture was clearly superior in all trials, mixtures 2 and 3 tended to give better results.

Mixture number 2 was dominated by three wheatgrass species, especially Agropyron dasystachyum (Table 11). Mixture number 3 was also dominated by A. dasystachyum; with the other three species in the mixture contributing relatively little plant cover. Mixture number 1

Table 10

EFFECTS OF SEED MIXTURE ON SIX VARIABLES IN THE FOUR SEED MIXTURE TRIALS

Mixture[1]	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
		- Plant Cover (%) -		
1	5.2b[2]	6.0a	6.0a	6.8ab
2	12.1a	8.7a	7.0a	8.9a
3	13.8a	8.9a	5.8a	8.4a
4	3.9b	6.6a	6.2a	5.1b
		- Biomass ($g/0.25m^2$) -		
1	2.55	4.11a	3.33ab	4.17a
2	3.95	4.75a	5.05a	5.04a
3	4.75	5.21a	3.11b	4.25a
4	0.44	3.06a	1.03	1.77
		- Species Richness ($no./0.25m^2$) -		
1	3.9ab	6.7ab	4.4a	7.8a
2	2.6b	5.5b	3.9a	7.5a
3	2.5b	5.3b	3.6a	5.7a
4	4.7a	8.4a	4.6a	7.7a
		- Vigor -		
1	2.3	2.9b	2.9a	3.7a
2	3.1a	3.1ab	2.9a	3.9a
3	3.3a	3.4a	2.5a	3.9a
4	1.9	2.9b	2.6a	3.7a
		- Litter Cover (%) -		
1	46.1	68.3ab	41.8a	43.0a
2	70.3a	72.1ab	44.2a	43.8a
3	62.6a	79.2a	38.4a	50.0a
4	14.9	54.2b	39.7a	38.9a
		- Bare-Ground Cover (%)		
1	53.5	30.4ab	57.5a	52.2a
2	28.8a	27.5ab	54.6a	53.0a
3	32.3a	20.2b	60.5a	48.0a
4	84.0	42.4a	58.4a	57.9a

[1] Native grass mixtures:
1. Agropyron trachycaulum, Festuca saximontana, Poa alpina, P. interior
2. A. dasystachyum, A. subsecundum, A. trachycaulum, Koeleria cristata
3. A. dasystachyum, Deschampsia caespitosa, P. alpina, Trisetum spicatum
4. F. saximontana, K. cristata, P. interior, T. spicatum

[2] Means followed by the same letter within a column for a given variable are not different at the 5% level of significance (N=15).

Table 11

MEAN PER CENT COVER (+ STANDARD ERROR) OF SEEDED NATIVE SPECIES IN THE FOUR SEED MIXTURE TRAILS (N=15)

Species	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
Mixture 1				
Agropyron trachycaulum	4.00±0.49	3.17±0.77	1.48±0.43	2.65±0.57
Festuca saximontana	0.60±0.16	0.22±0.05	2.48±0.89	0.08±0.08
Poa alpina	0.03±0.02	0.00	0.02±0.02	0.50±0.27
Poa interior	0.20±0.06	0.32±0.06	0.12±0.04	0.09±0.04
Mixture 2				
Agropyron dasystachyum	8.43±1.11	3.19±0.52	2.30±0.37	2.68±0.67
Agropyron subsecundum	0.00	0.01	0.00	0.00
Agropyron trachycaulum	2.37±0.67	2.43±0.45	0.93±0.43	1.48±0.63
A. trachycaulum/ subsecundum*	1.05±0.45	0.75±0.32	2.55±0.71	1.87±0.77
Koeleria cristata	0.22±0.12	0.48±0.18	0.80±0.20	0.79±0.30
Mixture 3				
Agropyron dasystachyum	11.83±1.39	6.97±0.73	2.97±0.87	4.00±0.70
Deschampsia caespitosa	0.00	0.00	0.27±0.16	0.00
Phleum alpinum	0.00	0.00	0.07±0.03	0.27±0.14
Trisetum spicatum	0.13±0.05	0.05±0.04	0.88±0.40	0.02±0.02
Mixture 4				
Festuca saximontana	2.20±0.47	0.58±0.22	3.22±0.84	0.35±0.12
Koeleria cristata	0.47±0.15	2.83±0.69	0.73±0.26	0.73±0.30
Poa interior	0.23±0.06	0.39±0.07	0.17±0.05	0.17±0.05
Trisetum spicatum	0.17±0.08	0.45±0.05	0.48±0.14	0.03±0.02

* Species sometimes could not be distinguished in vegetative form.

was dominated usually by A. trachycaulum. Mixture number 4 was the only mixture without a species of wheatgrass and generally gave the poorest results.

Thus, the wheatgrass species were the cover dominants, especially A. dasystachyum. Several species produced very little plant cover in these trials, including Deschampsia caespitosa, Phleum alpinum, Poa alpina, P. interior and Trisetum spicatum. With the exception of P. alpina, which was not tested, these species also did poorly in the adaptability trials at Cadomin (see Section 3.2).

The main effects of companion crops varied among the four trials and no consistent trends could be identified (Table 12). In most trials the effects of the companion crops were weak or nonexistent. An exception was the relatively high plant cover achieved by Alopecurus pratensis in the mineral soil trial at Adanac. On balance, however, there was little apparent advantage gained by including the companion crops in the mixtures. These results parallel those obtained after the first year of the study (Tomm and Russell 1981).

Perhaps one reason for the small effect of the companion crops was the low seeding rate used (5 kg/ha per species) relative to that of the native grass mixtures (17 to 107 kg/ha depending on the mixture). Increasing the seeding rate probably would have increased the cover of most of the companion crops.

In terms of plant cover Alopecurus pratensis and Festuca rubra 'Boreal' were the most successful companion crop species (Table 13).

Table 12

EFFECTS OF COMPANION CROPS ON SIX VARIABLES IN THE FOUR SEED MIXTURE TRIALS

Companion[1] Crop	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
		- Plant Cover (%) -		
A	9.2a[2]	8.6ab	5.9a	11.8
B	8.3a	4.3c	6.7a	6.9ab
C	9.2a	10.7a	5.4a	8.6a
D	8.4a	7.7b	6.9a	5.5bc
E	8.7a	6.5bc	6.3a	3.7c
		- Biomass ($g/0.25m^2$) -		
A	2.72ab	4.90a	3.09b	5.04a
B	3.00ab	3.58a	3.87a	4.67a
C	2.47b	4.41a	3.24ab	4.05ab
D	2.97ab	4.00a	2.66b	3.07bc
E	3.47a	4.54a	2.77b	2.21c
		- Species Richness ($no./0.25m^2$) -		
A	3.8a	6.1a	4.3a	6.8a
B	3.3a	6.8a	4.3a	7.1a
C	4.0a	5.4a	3.7a	6.8a
D	3.1a	7.2a	4.7a	8.1a
E	3.0a	6.8a	3.8a	7.3a
		- Vigor -		
A	2.8a	3.1ab	2.8a	4.0a
B	2.7a	2.6b	2.8a	4.0a
C	2.8a	3.4a	2.6a	3.8a
D	2.6a	3.1ab	2.8a	3.8a
E	2.6a	3.1ab	2.7a	3.7a
		- Litter Cover (%) -		
A	51.4a	68.1a	42.5ab	56.8a
B	53.8a	64.8a	49.6a	51.9a
C	48.3a	71.5a	42.9ab	43.0ab
D	42.8a	71.4a	39.5ab	45.3ab
E	46.0a	66.4a	30.6b	22.5b

Table 12 (continued)

Companion[1] Crop	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
	- Bare-Ground Cover (%)			
A	47.9a	31.6a	56.7ab	41.3a
B	45.4a	33.8a	49.3b	45.8a
C	50.8a	27.2a	56.6ab	53.8a
D	51.6a	26.8a	58.2ab	49.6a
E	52.6a	31.3a	68.3a	73.5

1 Companion Crops:
A. *Alopecurus pratensis*
B. *Phleum pratense* 'Climax', *Trifolium repens*
C. *Festuca rubra* 'Boreal', *T. Hybridum* 'Aurora'
D. *Lolium perenne* 'Norlea'
E. Control

2 Means followed by the same letter within a column for a given variable are not different at the 5% level of significance (N=12).

Table 13

MEAN PER CENT COVER (± STANDARD ERROR) OF COMPANION CROP SPECIES IN THE FOUR SEED MIXTURE TRIALS (N=12)

Species	Cadomin		Adanac	
	Overburden	Topsoil	Overburden	Topsoil
Companion Crop A				
Alopecurus pratenis	1.06±0.32	6.13±1.24	2.90±0.77	9.46±1.15
Companion Crop B				
Phleum pratense 'Climax'	0.19±0.08	0.56±0.18	0.90±0.28	2.94±1.00
Trifolium repens	0.00	0.06±0.04	0.00	0.00
Companion Crop C				
Festuca rubra 'Boreal'	1.40±0.38	5.42±1.16	3.10±0.67	4.00±0.91
Trifolium hybridum 'Aurora'	0.00	0.92±0.78	0.00	1.06±0.44
Companion Crop D				
Lolium perenne 'Norlea'	0.00	0.00	0.00	0.00

The legumes Trifolium hybridum 'Aurora' and T. repens gave poor results and Lolium perenne 'Norlea' failed entirely.

The three cultivated grass-legume mixtures generally performed no better and no worse than the four native grass mixtures (Table 14). None of the seven mixtures emerged as consistently superior. Native mixture number 4 was the poorest mixture in two of the trials but was no different from the other mixtures in the other two trials.

In cultivated mixtures a and c either Festuca rubra 'Boreal' or Agropyron cristatum 'Fairway' dominated in terms of plant cover (Table 15). F. rubra 'Boreal' was consistently dominant in mixture b. Phleum pratense 'Climax' was present in most plots in which it was seeded but its cover was low. Poa compressa, T. hybribum 'Aurora', and T. repens failed to develop a plant cover in most plots they were seeded.

The effects of soil medium on the six dependent variables are shown in Table 16. The most significant difference between the two soil mediums was that species richness was higher on mineral soil. This suggests the mineral soil was more favorable for species invasion. Plant vigor was slightly higher on the mineral soil than overburden; and in the Cadomin trials biomass was higher on mineral soil. The other variables did not differ significantly between the two soil mediums.

In the Cadomin trials observations suggested that plots with high litter and/or plant cover supported relatively few plant species. The lower growing species in the seed mixtures, in particular, appeared to be poorly represented. Correlation tests showed species richness

Table 14

EFFECTS OF NATIVE AND CULTIVATED SEED MIXTURES ON SIX VARIABLES IN THE FOUR SEED MIXTURE TRIALS

Mixture[1]	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
		- Plant Cover (%) -		
1	5.7cd[2]	5.0a	5.8a	2.6ab
2	11.7ab	6.5a	7.8a	6.1ab
3	16.2a	8.3a	5.5a	4.7ab
4	1.4d	6.6a	6.2a	1.3ab
a	9.3bc	8.5a	3.5a	12.3a
b	5.0cd	4.5a	4.2a	9.2ab
c	8.8bc	8.8a	3.2a	12.0a
		- Biomass (g/0.25m^2) -		
1	3.37ab	5.77a	2.77a	2.90bc
2	4.63a	3.67abc	4.23a	3.23bc
3	5.67a	4.23ab	3.50a	1.97c
4	0.20c	4.50ab	0.60a	0.73c
a	5.30a	2.23bc	0.67a	8.13a
b	1.03bc	1.13c	1.43a	2.93bc
c	4.33a	3.33abc	0.73a	6.23ab
		- Richness (no. species/0.25m^2) -		
1	3.3a	7.7ab	4.3a	7.7a
2	2.3a	5.7bc	3.3a	8.0a
3	2.3a	4.7bc	2.3a	6.0a
4	4.0a	9.3a	5.0a	7.3a
a	4.0a	4.3c	2.3a	5.0a
b	2.7a	5.0bc	2.7a	5.7a
c	3.7a	6.7abc	2.7a	5.7a
		- Vigor -		
1	2.7a	2.7a	2.7a	3.3a
2	3.0a	3.0a	3.0a	3.7a
3	3.3a	3.3a	2.3a	4.0a
4	1.3a	3.3a	2.7a	3.7a
a	3.0a	2.7a	2.3a	4.0a
b	1.7bc	3.0a	2.0a	3.3a
c	2.3ab	3.0a	2.3a	4.0a

Table 14 (continued)

Mixture[1]	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
		- Litter Cover (%) -		
1	58.5ab	67.0a	19.8a	15.7a
2	67.8a	77.5a	50.2a	28.0a
3	54.8ab	63.5a	23.3a	24.0a
4	3.0	57.7a	29.2a	22.5a
a	41.5bc	83.3a	45.3a	42.3a
b	23.7c	66.2a	22.0a	36.3a
c	46.2b	93.2a	61.0a	61.5a
		- Bare-Ground Cover (%) -		
1	40.7ab	31.3a	78.8a	76.8a
2	31.3b	22.2a	48.3a	69.8a
3	42.0ab	33.8a	75.5a	73.0a
4	96.5	38.0a	69.5a	74.3a
a	57.2a	16.3a	53.8a	59.8a
b	76.0	33.3a	76.3a	60.8a
c	53.3a	6.8a	38.2a	38.0a

[1] Native grass mixtures:
1. Agropyron trachycaulum, Festuca saximontana, Poa alpina, P. interior
2. A. dasystachyum, A. subsecundum, A. trachycaulum, Koeleria cristata
3. A. dasystachyum, Deschampsia caespitosa, P. alpina, Trisetum spicatum
4. F. saximontana, K. cristata, P. interior, T. spicatum

Cultivated grass-legume mixtures:
a. Festuca rubra 'Boreal', Trifolium repens, Phleum pratense 'Climax', Agropyron cristatum 'Fairway'
b. F. rubra 'Boreal', T. repens, P. pratense 'Climax', Poa compressa
c. F. rubra 'Boreal', Phleum pratense 'Climax', A. cristatum 'Fairway', T. hybridum 'Aurora'.

[2] Means followed by the same letter within a column for a given variable are not different at the 5% level of significance (N=3).

Table 15

MEAN PER CENT COVER (+ STANDARD ERROR) OF SPECIES IN THE CULTIVATED GRASS-LEGUME SEED MIXTURES IN THE FOUR SEED MIXTURE TRIALS (N=3)

Species	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
Mixture a				
Festuca ruba 'Boreal'	0.85±0.45	8.00±2.78	3.50±1.53	5.33±2.68
Trifolium repens	0.00	0.00	0.00	0.00
Phleum pratense 'Climax'	0.27±0.13	0.42±0.08	0.10±0.08	0.83±0.46
Agropyron cristatum 'Fairway'	6.83±0.73	0.58±0.33	0.00	6.83±3.24
Mixture b				
Festuca ruba 'Boreal'	4.83±2.89	4.50±0.76	4.00±0.29	8.17±5.17
Trifolium repens	0.00	0.00	0.00	0.00
Phleum pratense 'Climax'	0.25±0.14	0.25±0.00	0.25±0.25	1.08±0.96
Poa compressa	0.00	0.00	0.02±0.02	0.00
Mixture c				
Festuca ruba 'Boreal'	0.83±0.33	7.50±2.65	3.17±0.17	5.50±2.47
Phleum pratense 'Climax'	0.02±0.02	0.75±0.38	0.08±0.08	0.92±0.51
Agropyron cristatum 'Fairway'	8.17±1.96	1.00±0.38	0.00	6.17±0.60
Trifolium hybridum 'Aurora'	0.00	0.25±0.25	0.00	0.00

Table 16

EFFECTS OF SOIL MEDIUM ON SIX VARIABLES IN THE FOUR SEED MIXTURE TRIALS

Variable	Cadomin		Adanac	
	Overburden	Mineral Soil	Overburden	Mineral Soil
Plant Cover (%)	8.7a[1]	7.5a	6.2a	7.3a
Above Ground Biomass ($g/0.25m^2$)	2.92	4.29	3.13a	3.81a
Species Richness (no. species/$0.25m^2$)	3.4	6.5	4.1	7.2
Vigor	2.7	3.0	2.7	3.8
Litter Cover (%)	48.5a	68.4a	41.0a	43.9a
Bare-Ground Cover (%)	49.7a	30.1a	57.8a	52.8a

[1] Means followed by the same letter within a row for a given study site are not different of the 5% level of significance (N=3).

was negatively correlated ($P < 0.001$) with both litter cover and plant cover in both trials. Several explanations are possible: (1) competition offered by the plant cover reduced species richness; (2) the litter produced by the larger species, primarily the wheatgrasses, smothered the lower growing species; and (3) the litter cover served as a barrier to plant invasion.

This relationship was not observed in all trials. In the Adanac trials the correlations were not significant. In trials with a very high proportion of bare-ground cover the correlations were reversed. For example in the two nurse crop x fertilizer rate x seeding rate trials species richness was positively correlated with litter cover and plant cover ($P < 0.001$). Thus, in open areas with abundant bare ground, plant cover and litter cover tend to increase with the number of species present. This relationship apparently reverses when the community begins to close.

6.3 Conclusions

The most successful native grass mixtures were those containing wheatgrass species, particularly *Agropyron dasystachyum* and *A. trachycaulum*. The poorest mixture was frequently number 4, which contained no wheatgrasses. *Phleum alpinum*, *Poa alpina*, *Poa interior*, *Deschampsia caespitosa* and *Trisetum spicatum* produced little plant cover and may have established poorly and/or were outcompeted by the wheatgrasses.

The companion crops in general had small effect on the

performance of the native seed mixtures. The best companion crops in terms of plant cover were Alopecurus pratensis and Festuca rubra 'Boreal'. The legumes Trifolium hybridum 'Aurora' and T. repens gave poor results and Lolium perenne 'Norlea' failed entirely.

The cultivated grass-legume mixtures generally performed equally well as the native mixtures. The dominant species in the cultivated mixtures were Agropyron cristatum 'Fairway' and Festuca rubra 'Boreal'. Poa compressa and Trifolium hybridum 'Aurora' performed very poorly and T. repens failed completely.

Results from these and other trials at Cadomin suggest that in areas with high bare-ground cover plant cover and litter cover increase with the number of species present (richness). As the community begins to close there is less bare ground available for invasion and increases in plant cover and litter cover are associated with decreases in richness.

While most variables did not differ dramatically between the two soil mediums, species richness was consistently higher on the mineral soil than overburden. Thus, species invasion is apparently more successful on mineral soil.

7. ESTABLISHMENT METHODS TRIAL
(Established by S.K. Tayki. The earlier progress report was written by him.)

7.1 Methods

This trial was set up at Cadomin in June 1980 on overburden to test eight methods of establishing a native grass seed mixture. A complete randomized block design with four blocks was used. The seed mixture was composed of Agropyron trachycaulum (68.1% by weight), Festuca saximontana (14.5%), Poa alpina (9.3%), and P. interior (8.1%). The mixture consisted of equal numbers of seeds of each species and was sown at a rate of 46.1 kg/ha. Fertilizer (10-30-10) was broadcasted at a rate of 600 kg/ha and raked into the plots before seeding. No additional fertilizer was applied in subsequent years.

The eight treatments were as follows:

A. Broadcast Seed/Hold/gro Mulch

The seed mixture was broadcasted by hand, lightly raked in, and "Hold/gro" (the standard seeding type) installed according to the manufacturer's recommendations. The Hold/gro was held in place with metal staples supplied by the manufacturer. The edges of the Hold/gro were covered with overburden to prevent disturbance by winds.

B. Broadcast Seed/Excelsior Blanket Mulch

The seed mixture was broadcasted by hand, lightly raked in,

and Excelsior Blanket (AMXCO "Curlex") installed according to the manufacturer's recommendations. The material was held down with metal staples supplied by the manufacturer.

C. Broadcast Seed/Hydromulch

The seed mixture was broadcasted by hand, lightly raked in, and Conwed 200 paper mulch (87% organic material, 3% colloidal polysacharide tackifier, and 10% water) was applied as a slurry. The rate of application was 0.8 kg/plot (2 000 kg/ha), applied in two batches to ensure an even distribution of the mulch over the plots.

Each batch, containing approximately 0.4 kg of the mulch, was placed in a hydrograsser with 20 litres of water and applied to the entire plot. A Reinco hydrograsser (Test Plot Model PP-20L) was used.

D. Hydroseed with Paper Mulch

The plots were lightly raked and Conwed 200 paper mulch was applied with the native grass seed mixture as a slurry. The rate of application was 0.8 kg/plot (2 000 kg/ha), applied in two batches as described for treatment C.

E. Hydroseed with Organic (Grass) Mulch

The plots were lightly raked and Jacklin Organic Mulch was applied with the seed mixture and a tackifier (Terra Tack 1) as a slurry. The mulch was applied at a rate of 2 kg/plot (5 000 kg/ha). The rate of application of the tackifier was 16 g plot (40 kg/ha). The slurry was applied in two batches as in treatment C.

F. Broadcast Seed/Straw Mulch

The seed mixture was broadcasted by hand, lightly raked in, and the straw (barley) was evenly spread on the plot at a rate of 2.24 kg (5 600 kg/ha) per plot. The straw was held in place with the same nylon netting used by AMXCO to hold down the Excelsior Blanket during installation. The nylon net cover was stapled onto the spoil.

G. Drill (simulated) Seed

The plots were lightly raked, and 2 cm deep furrows were made with a rake in rows spaced 20 cm apart. The seed was distributed as evenly as possible in the furrows and overburden spread on top to cover the seeds.

H. Broadcast Seed

The seed mixture was broadcasted by hand and lightly raked into the surface.

The treatments and establishment methods are described in greater detail in Takyi (1981).

Sixth-year assessments were made August 15, 1985. The assessment methods and data analyses were the same as described in Section 3.1 except flower-bearing tiller density was not sampled.

7.2 Results and Discussion

The treatments had significant main effects on all six dependent variables (Table 17). In terms of plant cover the best results were achieved with the simulated drill seeding and the five

Table 17

EFFECTS OF ESTABLISHMENT METHOD ON SIX VARIABLES
IN THE ESTABLISHMENT METHODS TRIAL

	Plant Cover (%)	Biomass ($g/0.25m^2$)	Species Richness ($no./0.25m^2$)	Vigor	Litter Cover (%)	Bare-Ground Cover (%)
Broadcast Seed/ Hold/gro	18.5ab	12.97ab	2.5ab	4.3ab	58.8ab	33.6bc
Broadcast Seed/ Excelsior	18.3ab	10.07abcd	3.8a	4.0ab	59.0ab	38.6bc
Broadcast Seed/ Hydromulch	13.9abc	11.25abc	2.0b	3.5abc	33.5bc	65.3ab
Hydroseed/Wood Fibre	2.3c	1.42d	1.8b	1.5d	2.0c	96.6a
Hydroseed/Organic Mulch	4.4bc	2.50cd	2.0b	2.3cd	7.3c	81.4a
Broadcast Seed/ Straw	22.5a	11.72abc	1.5b	4.5a	83.3a	16.4c
Drill Seed	23.1a	18.12a	1.0b	4.3ab	66.1ab	33.6bc
Broadcast Seed	8.2abc	8.47bcd	1.8b	2.8bcd	22.0c	77.6a

broadcast seeding treatments. The effects on biomass were similar, except the drill seeding treatment gave significantly better results than the broadcast seeding without mulch treatment. The broadcast seeding/straw mulch treatment had the highest vigor and litter cover and the lowest bare-ground cover, although several other treatments were not significantly different.

Mean species richness was 1.3/0.25 m^2, which was lower than in any other trial in the study; perhaps reflecting the fact that mean plant cover was the highest in the study (13.9%). Among the treatments in this trial mean species richness was highest in the broadcast seeding/excelsior treatment and lowest in the drill seeding treatment (Table 17).

The poorest results were given by the hydroseeding treatments; in which the seed was applied in a slurry with the mulch. A common problem with applying the seed and mulch together is that the seed gets "hung up" in the mulch and does not contact the ground. Better results were achieved by applying the seed and fertilizer first, followed by the mulch (see treatment C).

The relative success of the drill seeding and broadcast seeding/mulch treatments compared with the broadcast seeding without mulch may be due to the greater degree of wind protection offered by these treatments. Seed loss by high winds has been observed in several of the trials at Cadomin where seed was broadcasted but not mulched (Russell and Takyi 1979).

Of the species in the seed mixture Agropyron trachycaulum was

overwhelmingly the dominant (Table 18). In fact 31% of the plots had only A. trachycaulum present.

This trial was assessed at the end of the first growing season for seed germination rate (Takyi 1981). The drill seeding treatment had the highest germination rate, followed by the four broadcast seeding/mulch treatments, and finally the broadcast seeding/ no mulch and two hydroseeding treatments. Five years later in 1985 the same general ranking of treatment means is true for plant cover and biomass.

7.3 Conclusions

The most successful methods of establishment were those that provided protection for the seed. The drill seeding and broadcast seeding/mulch treatments gave the best results. The broadcast seed/no mulch treatment leaves the seed exposed and generally was less successful. The poorest results were obtained when seed and mulch were applied together in a slurry using a hydroseeder.

Of the four species in the seed mixture Agropyron trachycaulum was overwhelmingly dominant in terms of plant cover.

Table 18

MEAN PER CENT COVER (+ STANDARD ERROR) OF SPECIES
IN THE ESTABLISHMENT METHODS TRIAL

Species	Mean	±	SE
Agropyron trachycaulum	11.53	±	1.87
Festuca saximontana	0.61	±	0.18
Poa interior	0.45	±	0.13
Poa alpina	0.25	±	0.16

8. INTEGRATION

Native species are generally less commercially available and more costly than cultivated species. Therefore the argument for using native species in reclamation is strongest in situations where cultivated species do not perform adequately or as well as natives. For example, when native species show superior adaptation to some environmental limiting factor(s).

The Cadomin and Adanac test sites were subalpine, windy, and periodically had low winter snow cover. Nonetheless, on these sites no apparent advantage has thus far been gained in using native grasses over cultivars. In terms of the measured variables the best species performed only fairly well; and no distinctions could be made between the best natives and best cultivars.

The Mildred Lake test site was milder climatically than the subalpine sites and most native and cultivated species performed reasonably well. Again, there was no apparent advantage in using native species.

Thus, the question of where native species should be used still remains. The results from this study suggest cultivated species can be used just as successfully as natives on subalpine sites. It may turn out that natives are only truly needed in more extreme sites, such as above treeline.

On the subalpine test sites the most consistently successful

species in terms of plant cover were: (1) native - Agropyron dasystachyum, A. trachycaulum, Festuca rubra and Koeleria cristata; and (2) cultivated - A. cristatum 'Fairway', A. trachycaulum 'Revenue', Alopecurus pratensis and F. rubra 'Boreal'. None of the cultivated legumes established well in the plots in which they were seeded, although Trifolium hybridum 'Aurora' and T. pratense were sometimes "invaders" in mineral soil plots downwind. Phleum alpinum and Trisetum spicatum performed very poorly on the subalpine test sites and thus may be poor choices for reclamation in similar situations. A low seed germination rate may have contributed to the poor performance of T. spicatum (Tomm 1982).

The wheatgrasses generally produced the greatest amount of plant cover and above-ground biomass and were usually considered the most successful species. However, they also produced the highest litter cover, which can have undesirable effects on community development. The lower growing species in the seed mixtures were often poorly represented in plots with high litter cover, suggesting they could not survive under the accumulated litter. Species richness was low in plots with high litter cover, suggesting the litter layer was a barrier to species invasion. Since community development (succession) proceeds by species invasion and enrichment, development of a high litter cover may slow the rate of succession.

In this regard Festuca rubra may be a good compromise species. It produced good plant cover but not a lot of biomass or litter. However, it performed poorly on the coarsest overburden.

The trials on mineral soil consistently outperformed their

counterparts on overburden, although the differences for most variables were often small. However, species richness was always substantially higher on mineral soil. Apparently the mineral soil was more favorable than overburden for species invasion, suggesting succession will proceed more rapidly on mineral soil.

In terms of establishing native grasses the best methods at Cadomin were those that provided the seed with some protection. Drill seeding and broadcast seeding followed by application of a mulch produced the highest plant covers. In most trials at Adanac and Cadomin the seed was broadcast but not mulched. The result was plant cover development was often poor and seed drift was common. The results from the establishment methods trial suggest plant cover could have been increased had a mulch been used. At Mildred Lake drill seeding was the only method used and it worked well for all species.

Broadcast fertilization at establishment time significantly improved the performance of a native grass mixture at Cadomin. The response to fertilizer rate was more dramatic on overburden than mineral soil, suggesting low fertility was more limiting on overburden.

With the exception of the seed mixture trials the trials in this study have not been fertilized since establishment. The seed mixture trials were re-fertilized once in the year following establishment but not since. Considering the strong response to initial fertilization at Cadomin, especially on overburden, it is likely native grass performances on this site could have been enhanced with regular maintenance fertilization.

Also at Cadomin the response to increasing the seeding rate

was small but significant after the first growing season, but had apparently disappeared by the second year. However the overall performance of the seed mixture in this trial (nurse crop x fertilizer rate x seeding rate) was so poor that little can be concluded about the effects of seeding rate.

9. RECOMMENDATIONS

1. The results of this study suggested that either native or cultivated grasses can be used successfully to reclaim subalpine coal-mined lands. The best cultivated species performed equally as well as the best native species. Thus, the decision to use native or cultivated species can be made on other factors, such as seed costs or the ability of a given species to perform a specific task.

2. The following species consistently produced the highest plant covers and thus were the best species for erosion control purposes: (1) native - Agropyron dasystachyum, A. trachycaulum, Festuca rubra, Koeleria cristata; and (2) cultivated - A. cristatum 'Fairway', A. trachycaulum 'Revenue', Alopecurus pratensis, F. rubra 'Boreal'.

3. Phleum alpinum and Trisetum spicatum consistently performed poorly in these trials and may be poor choices for high elevation reclamation.

4. The revegetation treatments were generally more successful on the native mineral soil than the coarser textured overburden. Most species produced higher plant cover on the mineral soil. Furthermore, the mineral soil supported substantially more plant species, indicating communities were more diverse on the mineral soil than overburden.

5. Topsoiling with 20 cm of native mineral soil appeared adequate to support the seed mixtures. The minimum depth of mineral soil needed was probably less than 20 cm; but this depth will likely vary with the properties of the mineral soil.

6. Fertilization at establishment time increased native grass plant cover. Although not tested in this study, additional applications of fertilizer in following years might further enhance plant cover development.

7. Whether it was because of their poor establishment or the low seeding rates used, most nurse crops and companion crops added little additional plant cover beyond that provided by the native grass mixtures alone. Since it was shown that native grasses, when established properly, can provide a reasonable amount of plant cover, the use of cultivated nurse or companion crops may be unecessary.

8. The most successful methods of establishing native grasses at Cadomin were those that covered and protected the seed. Drill seeding and broadast seeding followed by application of a mulch produced the highest plant covers.

LIST OF REFERENCES

Islam, M.R., and S.K. Takyi. 1984. Cadomin Reclamation Research Project: Third, Fourth and Fifth-Year Results. Alberta Energy and Natural Resources, Forest Service, Edmonton. ENR No. T/56.

Root, J.D. 1976. Physical Environment of an Abandoned Strip Mine Near Cadomin, Alberta. University of Alberta, Alberta Research Council, Edmonton. Bulletin No. 34.

Russell, W.B. 1979. Native Grass Seed Mixture Trials (1979). Alberta Energy and Natural Resources, Forest Service, Edmonton.

Russell, W.B., and S.K. Takyi. 1979. The Cadomin Reclamation Research Project: First Year Results (1978). Alberta Energy and Natural Resources, Forest Service, Edmonton. ENR No. 121.

SPSS Inc. 1983. SPSSx User's Guide. McGraw-Hill, New York.

Strong, W.L., and K.R. Leggat. 1981. Ecoregions of Alberta. Alberta Energy and Natural Resources, Resource Evaluation and Planning Division, Edmonton. ENR No. T/4.

Takyi, S.K. 1980. Influence of Roll-out Mats and Ridging on the Establishment of Plant Cover on an Unamended Coal Spoil: A Progress Report for 1979. Alberta Energy and Natural Resources, Forest Service, Edmonton. ENR No. 152.

-----. 1981. Methods of Establishing Native Grasses on Coal Overburden: First Year Report (1980). Alberta Energy and Natural Resources, Forest Service, Edmonton.

Takyi, S.K., and W.B. Russell. 1980. The Cadomin Reclamation Research Project: Second-Year Results. Alberta Energy and Natural Resources, Forest Service, Edmonton. ENR No. 155.

Tomm, H.O. 1982. Establishment Report on the Mildred Lake Native and Cultivated Grass Reclamation Trial. Alberta Energy and Natural Resources, Forest Service, Edmonton.

Tomm, H.O., and W.B. Russell. 1981. Native Grass and Cultivated Grass-Legume Seed Mixture Trials on Subalpine Coal-mined Disturbances in Alberta: A Progress Report for 1980. Alberta Energy and Natural Resources, Forest Service, Edmonton. ENR No. T/21-80.